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ABSTRACT

Conceptually, the laboratory approach is based on Maria Montessori's and Jean Piaget's theories that students learn through becoming involved and experiencing mathematics. Teaching them means creating situations where structures can be discovered and where students can verify and relate ideas to objects. Following a discussion of definitions and theories pertaining to the mathematics laboratory, this document examines several additional topics pertaining to a laboratory setting: (1) arrangements and procedures; (2) materials; (3) curriculum sources; and (4) illustrative laboratory problems, games, and exercises. Finally, the document examines computer-assisted instruction (CAI) and several studies assessing laboratory effectiveness. Overall, 44 percent of these studies show that the laboratory approach is superior to expository methods, with the superiority distributed across all grade levels. It is concluded that the laboratory and CAI programs are valuable tools when used appropriately in the educational environment.
(Author/JN)

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THE MATHEMATICS LABORATORY AND
COMPUTER-ASSISTED INSTRUCTION

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ABSTRACT

Conceptually, the laboratory approach is based on Montessori's and Piaget's theories that students learn through becoming involved and experiencing mathematics. Teaching then means creating situations where structures can be discovered and where students can verify and relate ideas to objects.

Following a discussion of definitions and theories pertaining to the mathematics laboratory, the document examines several additional topics pertaining to a laboratory setting: (1) arrangements and procedures, (2) materials, (3) curriculum sources, and (4) illustrative laboratory problems, games, and exercises.

Finally the document examines computer-assisted instruction and several studies assessing laboratory effectiveness. Overall, the studies cited in this document show that the laboratory approach is superior to expository methods in 44% of the studies with the superiority distributed across all grade levels. The article concludes that the laboratory and CAI programs are valuable tools when used appropriately in the educational environment.

INTRODUCTION

The foundation of advancement is change. A jet plane multiplies an individual's rate of motion by a factor of 10^2 ; a radio wave accelerates the velocity of a human voice to a power of 10^6 . And in education, contrasted to 15 years ago -- the access to knowledge has been increased by 10^8 power. The retrieval time in a computer for 2000 monographs is $\frac{1}{2}$ second. ⁽¹⁾

Thus it is not surprising amidst a world of technical change to find dramatic alterations proposed for the structure of American education. In a White House conference on math education in October of 1971, the delegates concerned with elementary education stated there was a feeling that the existing educational system had not been successful with a distressing large number of children and that alternatives in education needed to be tried. ⁽²⁾

In international conferences, ministers of education and leading educational authorities from 86 countries stated that education must be closely related to real life. Especially called for were improvements in math teaching at the secondary level. ⁽³⁾

Articles in various American journals have called for more dislocation of existing patterns. ⁽⁴⁾ Individuals have called for revision of the learning environment. ⁽⁵⁾

What then has been the result of all this? Leaders in society have gone to their drawing-boards, so to speak, and sought sound educational theories as spring boards to improve mathematics education.

Tying together concepts of Montessori and Piaget, a model of human learning has been constructed. Into this system the force of change has been positioned.

Montessori stated that children pass through levels in development in which their minds are ready to receive information. ⁽⁶⁾

Piaget's theories dealt as well with the interaction of a child to his environment. Piaget hypothesized that young children learn through becoming involved, through acting, and through experiencing mathematics rather than "learning it" from a book. ⁽⁷⁾

Piaget stated that children younger than 11 or 12 do not acquire concepts by analytic thinking but by organizing and adapting them from their perceptions gained through interaction with the physical world. Furthermore there exist sequences in the acquisition of concepts with certain concepts being acquired at approximately the same age by most children.⁽⁸⁾

Cross-cultural studies of children in primitive societies in Aden and Nigeria⁽⁹⁾ yielded results very similar to those studies of European and American children. As a result of such multinational studies, today there exists a body of knowledge regarding ages at which one can expect most children to attain cognitive levels.

If children really do conceptualize by organizing and adapting perception of concrete, physical experiences, then a procedure which assists in this process would seem to be on firm ground.

This firm ground was furrowed by Piaget in a speech at Cornell University in 1964:

Teaching means creating situations where structures can be discovered; it does not mean transmitting structures which may be assimilated at nothing other than a verbal level...The teacher must provide the instruments which the children can use to decide things by themselves. Children themselves must verify, experimentally in physics, deductively in mathematics.⁽¹⁰⁾

The best method of teaching mathematics would by assumption be one to increase not only math achievement but to improve the attitude of the students.⁽¹¹⁾ One might use teaching aids, for the idea of using manipulative materials in teaching reaches back to 1855.⁽¹²⁾

Further, environment is helpful. One author stated environment would do far more good than traditional teaching methods to build enthusiasm, to teach students to use their own ingenuity, and to relate ideas to objects.⁽¹³⁾

Amidst the volume of theories, the laboratory approach has surfaced as a model for teaching mathematics. Such a model, concepts of Piaget that children learn through experiencing, follows.

THE MATHEMATICS LABORATORY

Experience has shown students remember $1/10$ of what we say, $1/4$ of what they see, and $1/2$ of what they do.⁽¹⁴⁾ This is the kernel of discovery teaching (laboratory activity) -- the student is to participate and learn through his or her reactions and responses to experiences. The aim of teaching is to direct students toward becoming thinking individuals. In a math laboratory, the student is given a series of questions with selected exercises to help direct him or her toward math goals. The lab approach then is a tool to assist in that process.⁽¹⁵⁾

Another author has defined a math lab as essentially three things -- a place, a process, and a procedure. It is a place in the sense of being a room set aside for math experiments and practical activities. It is an approach (process and procedure) which is informal in manner with students making findings, roving around, choosing materials and methods and discovering math for themselves.

Organization is involving a whole class at a time, say once per week, or only part of a class at a time. The student content is individual work, pair or group activity (2 or more). Generally unless some specific assignment is in mind, students can choose groupings for themselves.⁽¹⁶⁾

Another author has stated a mathematics laboratory is an approach rather than a place. That approach is exploring, investigating, hypothesizing, experimenting, generalizing, and doing math at a concrete level.⁽¹⁷⁾ This same author notes that students need to go through concrete levels of learning before they can reach higher levels of abstraction. Thus a lab should set the concretionary level, the student working at his or her own rate, going as far as possible to broaden his mind.⁽¹⁸⁾ There are various types of math laboratories for the elementary school.

One author suggests a three-station method with each learning station including several hands-on activities.⁽¹⁹⁾ Color coded red, blue, and green -- the stations are for measurement activities.

The red station shows measurement by comparison of like units, using hands and feet to measure various objects. The blue station allows students to use inches to measure and thus understand more about standard measurements. The green station introduces weighing. Students are to estimate weights and then check a balance scale. A bonus station is provided for the fast learner -- it includes puzzles and discovery experiments dealing with measurement. The stations are taken on a rotating basis; 3 days are required at each station.

Each child keeps a folder for teacher evaluation of progress. Evaluation charts are also used at the end of each unit of work.

Other planners are less formal. They advocate class corner labs. The teacher is to provide background information, then the students use the minilab for their own work. This could include using flash cards for drill too.⁽²⁰⁾

Still other educators see using an elementary lab as an opportunity for students to play math games.⁽²¹⁾ A very structured elementary program was developed at the Leon E. Slavens Elementary School in Denver.⁽²²⁾ This program was developed for the 4th, 5th, and 6th grades.

The math text and lab complemented each other. Together they provided a broader and more far-reaching program, thereby permitting a greater range of experiences for the students.

The lab specifically served several purposes: (1) a child could get individual remedial help; (2) a child could go research a math problem and investigate independently; (3) a child could find challenging instructional activities including puzzles and games; (4) children could help each other; and (5) media storage was in the lab.

In developing the program, school officials asked for PTA volunteers to serve as aides. These aides operated audiovisual equipment and tutored students. The lab was open 9 AM till 3 PM.

Materials were sorted into 10-color-coded categories:

1. General supplies - paper, pencils, erasers, grease pencils, graph paper, rubber bands.
2. Audiovisual materials - kits, filmstrips, tapes, records.
3. Books - textbooks, math books.
4. Measuring devices - scales, balance beams, rulers, walking yardsticks, cubic units, volume containers, vector sticks.
5. Geometric devices - geoboards, geoblocks, algebraic geoboards, protractors, compasses, booklets.
6. Graphing materials - graphing kits, maps.
7. Computing devices - adding and calculating machines, slide rules, Napier's rods.
8. Concrete representations of fractions, decimals, percents, magnetic parts, fractional parts kits, conversion devices.
9. Counting devices - abacuses, counting frames, Cuisenaire rods, multi-base abacus, chips, dice.
10. Games and puzzles.

Students were grouped into 3 categories: remedial, accelerated, and average.

Students were placed in each category by testing and by teacher recommendations.

The first year of lab operation, 1/5 of the fifth and sixth grades were helped as well as a few fourth grade students. Each child spent at least $\frac{1}{2}$ hour per week in the lab. The work was assigned individually or to groups of 2 or 3 students. At the beginning of lab practice, the math teacher gave assignments; later more freedom was given to the students. Later also Title III funds were used to purchase table-top computers.

It was felt enthusiasm and self-confidence were much improved. Test scores revealed marked increase compared to students with no lab training. Increases were especially apparent in concept application/s.

Finally in elementary lab construction, the role of the lab teacher is specifically defined (this being a product of 8 elementary lab programs in Chicago):

- (1) create relaxed atmosphere; (2) lead the children to discover relationships;
- (3) set materials up in the activity centers prior to the arrival of pupils in the lab; (4) tape directions for lab activities that will present reading problems caused by technical vocabularies; (5) write activity cards (cards giving directions for experiment to be performed) and directions; (6) determine individual weakness of students and assign appropriate lab activities; (7) correlate activities with

those of the classroom teacher; (8) determine groupings; and (9) encourage work in research and individual projects. (23)

For further information of the design of Chicago's elementary labs one should address queries to: Doolittle East Math Lab, 525 & 35th St., Chicago, Illinois 60616 or Math Consultant, Area B office, Curriculum Services, Edwards School, 4315 S. Karloo Ave., Chicago, Illinois 60632.

For junior high school labs, one example was a project in British Columbia. (24) Grades seven and eight of a large urban junior high school were used. Random selection placed students into one of three groups: Group I - math lab group; Group II - class demonstration and class discovery group; and Group III - control group taught regular class program.

The lab group performed 10 lessons in the math laboratory: (1) area and perimeter; (2) intersecting sets; (3) symmetries of a square; (4) area of polygons; (5) how many subsets; (6) mathematical balance; (7) numeration in base 3 and 5; (8) probability; (9) measurement of a circle; and (10) polyhedra. Each lab lesson occupied one period a week in place of the regular class.

This was a limited time program of 3 months. Although follow-up testing did not show significant statistical differences in grade level achievement for the math lab group, that group did score much higher in cumulative achievement transfer (higher level thinking and problem solving) than the control group, scoring highest in divergent thinking.

Now let us look at secondary mathematics laboratories. They are indeed diverse in construction. In one program, a semi-laboratory approach was used to supplement the math program. This approach consisted of 20 lab experiences. Each experience had prepared materials and work sheets. This program for slow learners in geometry used math investigations of mirrors and volumes among others to supplement the textbook. (25)

Another approach is the minilab. It is located in a corner of the room on a table. Materials might be uncooked spaghetti, sugar cubes, tin cans, baby food jars, rubber bands, drinking straws, or pipe cleaners. The teacher demonstrates the use of these materials in constructing math experiments as the students watch.⁽²⁶⁾

A more formalized program is the math laboratory at Sir R.L. Borden Secondary School in Scarborough, Ontario. Students participated in shop classes $\frac{1}{2}$ day and academics $\frac{1}{2}$ day. The math lab consists of an integration of filmstrips, teaching aids, tape recordings, records, transparencies, desk calculators, workshop material, and programmed learning materials. Each math room had math-builder projects, a filmstrip projector, an overhead projector, a cart and screen, and a Science Research Associates (SRA) computational skill-building kit. Also available was a film-loop projector, a class set of 12 calculators, a filmstrip receiver, tape recorder, record player, movie projector, and an opaque projector. The variety of equipment is used to inspire the students to learn.

The math course is divided into topics to be taught, each covering 4-to-5 weeks' duration. Each topic is concluded with a project week wherein students may work individually or in pairs to research practical applications of the preceding topic covered.⁽²⁷⁾

For additional information, one may write: Sir R.L. Borden Secondary School, 200 Poplar Rd., West Hills, Scarborough, Ontario.

Furthermore, in a laboratory, the teacher might wish to introduce math activities not necessarily tied directly to classroom work. Illustrations follow.

The following problem has a simple solution if the student is taught the following powers of 3: $3^1=3$, $3^2=9$, ..., $3^5=243$, $3^6=729$, $3^7=2187$, $3^8=6561$, $3^9=19683$, $3^{10}=59,049$.

$$\begin{aligned} \text{The problem: } \frac{(6561)^2 \times (243)^3 \times 729}{(19,683)^2 \times 59,049} &= \frac{(3^8)^2 \times (3^5)^3 \times 3^6}{(3^9)^2 \times 3^{10}} \\ &= \frac{3^{37}}{3^{28}} = 3^9 = 19,683. \quad (28) \end{aligned}$$

Try this card trick. Deal 2 stacks of 26 cards each from a deck of 52 cards. Call one deck "A" and the other "B". Count down 7 cards and show the card to the students, yourself not seeing it. Put these cards back on the deck just as you took them off. Now take the deck you have not picked-up and deal the top 3 cards face up in a row in front of you. Each of these is the top card of a column of cards. You are to make each column add up to ten in the following manner: face cards = 10; others = value of the card; aces = 1. Next pick up the pile of cards in front of you and place the remaining cards from the deck used to make the 3 columns on top of the full deck (deck you counted 7 down from and showed card to students.) Now you count down the total number of cards to which the 3 top column cards add to. Where you stop will be the card you showed to the students.

An accelerated class or algebra II class might try to derive the algebraic equations to show why such a "trick" is mathematically valid. (32)

Another exercise is to turn up the top card of a regular deck of 52 cards. Begin counting from the face value of that card, turning up from the deck till you count through 13: (aces=1, jacks=11, queens=12 and kings=13). Next, after you reach the number 13, take another card off the deck and do as before. Repeat this until you have used all cards or you do not have enough to reach 13. Turn all piles face down.

Finally ask an observer to turn up the top cards of 2 of 3 piles which he is allowed to take from all the stacks. You take all the other stacks left and make them into one stack. Now add 10 to the sum of the 2 cards he turned up. Remove that many cards from the discard pile (your stack). The number of cards remaining in your stack is the value of the top card in the 3rd deck the observer has not turned over. Again this "trick" is a mathematically based system. A good class could try to put the algebra together to understand the why of the trick. (33)

Another application of algebra is illustrated in the following: you have 4 pennies to toss; the algebra is represented by the equation of $(h + t)^4$ where h = a head and t = a tail; the 4th power is the four pennies. Now: $(h+t)^4 = 1h^4 + 4h^3t + 6h^2t^2 + 4ht^3 + 1t^4$.

The h^4 means 4 heads; $4h^3t$ is hhht, thhh, hthh and hthh; the $6h^2t^2$ is hhtt, thth, htth, tthh, thht, htth. Thus the probability of obtaining 4 tails (t^4) is $1/16$ where the 16 is the sum of all the terms in the expansion $(h + t)^4$. This is a good project and also a 3-dimensional cube can be constructed as a model for three dimension algebra. (34)

Still another problem is illustrated: Ask a girl, for example, to write down the date and the month of her birth. Suppose it is the 3rd of August. She will write down 38 (3rd day and 8th month). Tell her to multiply this by 2; to add 5; to multiply by 50; to add her age; and finally to add 365. Then ask her to give you the result. Subtract 615 from this result, and you have the whole story. The first digit on the left will give you the date of the month; the second digit, the month; and the last two digits, the age. (35)

In addition in a math lab one might wish to go into procedures for out-of-class investigations. Such illustrations follow: look for symmetry in nature as 3 petalled trillium, 4 petalled dogwood, 5 petalled blossom mountain laurel or fruit trees or 6 petalled lily, iris or jounquil. This is a beginning to developing an observative mind. (36)

Inquiry is also developed as follows: describe properties. Find a small object such as a pebble, leaf, flower, insect, seed, fruit or vegetable; examine it carefully to find properties, structure, size; sketch or trace it and label the parts; measure and record characteristics as length, width, color, texture; describe how to identify it from a member of another set; what math applies to it besides its measure, design, classification; where one can find further information about it.

Describe a building's shape, size, height, volume, floor area, wall area, and window area. Describe an automobile's shape, size, wheels, gear ratio, compression ratio, cylinder volume, speed, or pollution.

Describe tools by shape, mechanical advantage (a math lab experiment), or force. Look at advertising as design, size, hidden assumptions, or variation in price. (37)

From the aforementioned, one can see the concept of a math lab is diverse. The selection of the type of lab one desires depends largely upon the quality of students dealt with, the desired goals, and the subjects taught. It is known for example that low ability students benefit more from concrete aids than do high ability students. (38)

Also it is felt teachers who individualize instruction are more likely to consider young people's self concept and attitude toward subjects. There is an increasing amount of evidence if one increases self concept, academic improvement almost automatically follows. If one has this quality of aid in a math lab, he or she would probably adjust well to individual instruction in vocational classes and thus be prepared more for a self-directed life in the world of work. (39)

Thus one might want one level of students to bring supplies from home and the teacher lead the math class in the construction of experiments; or one might wish to devise a package of say 12 math experiments to be done one each week and requiring one day of class work each experiment; additionally one might wish to stock a math room with a large amount of math equipment and at the end of a topic of formal study, have 3-or-4 days to investigate concepts in that particular chapter of the textbook. Further a math lab might be constructed for much math drill work. In this case the use of computer-assisted instruction would be ideal. Also one is not necessarily expected to exclude the elementary and/or middle school math lab constructions for application in type to the secondary mathematics program.

The following sources list programs and illustrate the varieties in math laboratories: Mathematics Achievement Improvement Program in Birmingham, Alabama.

Supervisor Sec. Math
Birmingham City Schools
400 Adm. Bldg.
Birmingham, Alabama 35202

Individual Advancement Lab. Prog. in Math.

Consultant, Math
Long Beach Unified School District
Board of Ed. Bldg.
701 Locust Ave.
Long Beach, California 90813

Outstanding Math. Lab. Facilities in Los Angeles Schools

Mathematics Specialist
Instructional Planning Branch
L.A. Unified School District
P.O. Box 3307
Los Angeles, California 90054

A Sequential Approach to Individ- ualization of the Mathematics Program

Los Angeles City Schools
Special Education Branch
Instructional Program
450 North Grand Avenue
Los Angeles, California 90012

TTT Mathematics System Laboratory

San Fernando Valley State College
18111 Nordhoff Street
Northridge, California 91324

Project FOCUS - Mathematics

Supervisor of Mathematics
New Haven Public Schools
One State Street
New Haven, Connecticut 06510

Projects in Mathematics for the Under- achiever and/or Slow Learner Involving Staff Members of the University of Connecticut

Robert A. Shaw
University of Connecticut
Storrs, Connecticut 06268

A Criterion for the Selection of Mathematics Curriculum for Low Achievers

Supervisor, Secondary Mathematics
Hillsborough County Public Schools
Instructional Services Center
707 East Columbus Drive
Tampa, Florida 33602

A Mathematics Resource Center, the Key to Improve Curriculum

Project Director
School District 91
150 North Water
Idaho Falls, Idaho 83401

Upward Bound, Southern Illinois University

Director, Upward Bound
Box 54-A
Southern Illinois University
Edwardsville, Illinois 62025

Readiness for Mathematics

Coordinator of Mathematics
Fayette County Schools
Lexington, Kentucky 40503

Resource Center for Low Achievers in Mathematics, Grades 7-9

Mathematics Consultant
Lafayette Parish School Board
P.O. Box 2158
Lafayette, Louisiana 70501

Using a Laboratory Setting for Slow Learners

Mathematics Supervisors
Montgomery County Public Schools
Educational Services Center
850 North Washington Street
Rockville, Maryland 20850

The Oakland County Mathematics Project

Project Director
Oakland Schools
2100 Pontiac Lake Road
Pontiac, Michigan 48054

Mathematics Experience Program

Project Director
Washington Junior High School
Lake Avenue and Third Street
Duluth, Minnesota 55806

Project SOSO (Save Our Slow Ones)

Director
Mathematics Department
Delta State College
Cleveland, Mississippi 38732

I.P.I., Grades 1-6 at Washington School

Washington School
Emory Avenue
Trenton, New Jersey 08611

Plus Program Mathematics

Administrator
Plus Program Mathematics
Buffalo Public Schools
Room 432, City Hall
Buffalo, New York 14202

The Development of Mathematics
Materials in Cincinnati for Low-
Achieving Pupils in Grades 7 and 8

Cincinnati Public Schools
Education Center
230 East Ninth Street
Cincinnati, Ohio 45202

The Philadelphia Low Achiever
Mathematics Project

Project Director
West Chester State College
West Chester, Pennsylvania 19380

MCLL 'Pops' into the Classroom

Lead Teacher
Mathematics/Science Component
Memphis Community Learning Laboratory
370 South Orleans Street
Memphis, Tennessee 38126

On Building a Program of Instruction for
the Low-achieving Mathematics Student

Consultant, Secondary Mathematics
El Paso Public Schools
100 West Rio Grande Avenue
El Paso, Texas 79999

Tailoring Teaching to Tantalize and
Tease Tense Teenagers

Coordinator of Mathematics
Henrico County Schools
Highland Springs, Virginia 23075

Milwaukee Project

Supervising Teacher
Milwaukee Public Schools
P.O. Drawer 10K
Milwaukee, Wisconsin 53201. (40)

East High School Mathematics Laboratory

East High School
515 N. 48th Street
Phoenix, Arizona 85008

Islands of Continuous Progress (Math)

P.O. Box 1358
Grand Forks, North Dakota 58201

Phoenix Union High School Math Lab

Phoenix Union High School
212 East Van Buren Street
Phoenix, Arizona 85004

St. Bernard Parish Nongraded Individ-
ualized Project

Assoc. Supt. St. Bernard Schools
Chalmette, Louisiana 70043. (41)

Instructional aids in lab follow:

Geometric Exercises in Paper Folding,
T. Sundara Row, (New York: Dover Pub-
lications, 1966).

Explorations in Mathematics, Robert B. Davis,
(Reading, Massachusetts: Addison-Wesley
Publications Co., 1966), for grades 4-8.

Number Patterns, by Wm. H. Glenn, (Manchester
Mo.: Webster Pub. Co., 1960), grades 8-11.

Lab Manuel for Elementary Math, W. Fitzgerald
(Boston: Prindle, Weber & Schmidt, 1969),
grades 5-12.

Experiments in Math. Stage 3, by J.F.F. Pearce
(Boston: Houghton Mifflin Co., 1966, 1967),
grades 5-12.

Mathematical Discovery, vol. 1, George Polya,
(New York: John Wiley & Sons, 1962),
grades 8-12.

A summary source as follows lists 50 books
and 5 journals considered most essential
in a library for teachers of math:

NEA Publication-Sales Section
1201 Sixteenth Street, NW
Washington, D.C.

A current math booklist for high school:

Mu Alpha Theta
University of Oklahoma
Norman, Oklahoma. (42)

COMPUTER-ASSISTED INSTRUCTION

The use of a computer in school is called CAI or CAL (computer-assisted learning). Various educators posit that, with the use of a computer or calculator, the student is able to concentrate on the process of problem solving and does not have to go through drudgery in computation. For solving algebra problems like $ax^2 + bx + c \neq 0$, the student is required to write his program (outline) and have some understanding of operators (like radicals signs for example). The computer then solves the problem and avoids much drudgery in detail.

One writer lists other uses of a math computer:

1. preparation of instruction materials
2. reinforcement of concepts by means of simulation of physical, social, economic, political and business systems (for example, by playing computer-based economic or political games the student makes decisions based on the knowledge of the factors that influence the situation)
3. acquisition and storage of student information (responses)
4. retrieval and presentation of information stored within the system
5. administrative data processing; record keeping, counseling, and research. (43)

Another author, Robert Lewis, states the present thinking as to the use of the computer is as a manager, not an instructor. In the British Times Educational Supplement, Lewis advocates using a computer to demonstrate concepts and solve problems. The essential aspect, he states, is guidance which can be given in terms of the organization and strategy necessary to support classroom activity. The computer is especially valuable for the math lab or project work as opposed to traditional teaching, he maintains. His idea is of the computer as a "handmaiden." (44)

Another writer advocates using the computer to do research. Thomas Kieren says seventh graders can write computer problems using BASIC. (45)

In the Journal of Educational Data Processing, Lee Lewellen suggests using the computer in four basic ways: (1) drill, practice; (2) computational aid - labs for science, math, business; (3) gaming and simulation of real life situations; and (4) instruction with television. (46)

William S. Dorn states the following pertaining to computer use: (1) computation aid; (2) algorithmic instructor - the discipline necessary in structuring a problem for computer solution measurable improves the students' problem-solving skills; (3) increased understanding of math concepts through writing programs; (4) use as a demonstration device - to allow the illustration of principles which otherwise would not be exemplified, as exploration, discovery; and (5) motivation. (47)

In yet another article in the Math Teacher, the use of the computer as a facilitator in instructional management is advocated, the teacher being relieved of the mammoth clerical burden associated with teaching. (48)

In a special report by the National School Public Relations Association, the statement is made that the computer is expected to aid but not to replace the classroom teacher. (49)

Now how exactly is the computer used? In one program in England, a one year experimental program was designed for first year secondary students. Students at the Hatfield School were taught at their own rates of learning by using computer support. Math lessons were videotaped on a Dec System 10 computer at Hatfield Polytech (England) and shown in part or full when needed.

Each three week tape was supported by a dozen or so work sheets. With no two work sheets alike, each was designed for individual students. (50)

A standard approach in the United States has been to use several terminals and other auxiliary devices connected to a central computer. These terminals may involve many different kinds of equipment, such as visual screens, typewriter boards, audio-instructional devices or even films or slides synchronized with terminal display of programmed materials (use of computer languages like INFORM permits teachers to then prepare the curriculum without special knowledge of programming or computer skills). (51)

One such system is the PDP-8/1 computer by the Digital Equipment Corporation. This third generation (integrated circuit) instrument has a teletypewriter connection to the computer and is linked to the operator's console.

An article in School Science and Mathematics, discusses the linking of student keyboards to computers. In addition a pen with a light on the end is used to point to answers on a display screen in response to questions on a video screen. This type of CAI unit can be used for drill (addition, subtraction, multiplication, division, decimals), and tutorial programs in French, chemistry, logic, or civil engineering. Other uses are solving a^2 or a^3 with $a = 1, 2, 3, \dots$; $c = a + b$; $A = L \times W$; others. (52)

Another type of CAI system is explained. This system is mainly tutorial in nature. A sample problem would be; if a rectangle is 5 feet wide and 12 feet long, what is the length of its diagonals? Answer choices might be $a=5$, $b=12$, $c=25$, $d=144$, $e=169$, or $f=13$. The student types out his or her answer on the console and then a colon; the colon is the command signal for the computer to evaluate the answer. (53)

An article in School Review describes another system. A student taking a drill-and-practice lesson uses a teletype which is alternately controlled by the computer and the student. The computer directs the typing out of the problem, positions the teletype to receive a response, and turns control over to the student. The student responds using the modified typewriter key board of the teletype. For most problems, the computer regains control as soon as the answer has been typed, examines the answer, and either moves on to the next problem, if the response is correct, or responds with an error message as 'no, try again.'

For other problems, such as those involving word meanings, the student may execute a series of steps, using the computer as a calculator. (54)

Seeing the diversity of computer use, what are the methods of setting up computer operation? The first is courier service to a computer center. This is recommended for a school just beginning a program dealing with computers. The disadvantage is the delay in the running time of the programs. The advantages are low cost, no capital investment of the school, and the professional assistance available.

The second is to transport students to a computer center. The disadvantage is the student use of the computer is slow and inefficient because of travel time.

The third is telephone connection to a computer. The disadvantage is the initial cost of telephone equipment and the monthly cost. The advantage is faster turn-around than by courier service and the motivating effect of student operation of the transmitting device.

The fourth is acquire a computer. If the computer is old (because the district purchased an older model), then the machine language and programming would be inefficient and very time consuming. Often such a language is impractical, the machine is limited in terms of programs per hour, and the cost of usage is high. Also upkeep is usually high.

The fifth is a remote console at the school that permits direct control of a computer located elsewhere. This is probably the most feasible possibility. The disadvantage though is the console cost plus the monthly charge. The advantage is the low cost compared to the acquisition of a computer.⁽⁵⁵⁾

Though larger computers and/or school computers are useful, they are expensive. Therefore it is not surprising to find many agreeing that such computer utilization is too costly for its value to the student. The same type of teaching can be done with teaching machines or programmed books.

It is also possible that a school system might want to purchase a smaller computer unit. Such a computer might have 12-to-15 student terminals (consoles). Each student would have a keyset at which to respond and an individual television display. Such a system was used in Champaign, Illinois, as a part of Programmed Logic for Automatic Teaching Operations (PLATO) project at the University of Illinois at Urbana. The system was designed to supplement the math curriculum.⁽⁵⁶⁾ It was an enrichment tool used in conjunction with topics of study.

If finances limit this type of unit, other smaller units are available. A possible unit is a programmable calculator, such as the Hewlett-Packard Models. Instruction and data are stored internally in a magnetic-core memory. This unit can evaluate trigonometry functions and convert rectangular to polar coordinates among other operations and has a special unit used manually as a calculator or automatically as a stored-program computer.⁽⁵⁷⁾

The Hewlett-Packards, among others, with optional card readers read information from punched cards which have been prepared by marking preprinted boxes with an ordinary pencil.

This equipment has sufficient capability for almost every instructional facet and may be used in vocational programs involving computers.

Teaching machines are nominal in cost. There are many which are currently sold.

Also to be considered are portable electronic Hand calculators. This method allows a check of accuracy in math problems and/or precludes this type pencil work entirely. It does eliminate tedious, unnecessary calculations which consume time. Calculators also permit one to get answers to processes not yet studied by the student. (5)

For summary then, it seems because of expense, a larger computer unit would not be practical. Renting time on a distant computer is wise. Also student consoles and individual T.V. display units would be feasible (especially for drill work). Also portable computer units are in wide use. Also hand-operated calculators (electronic) and math programmed materials have their place in secondary schools.

Computer facility selection depends upon finances available, results desired, and student level.

STUDIES ASSESSING LABORATORY EFFECTIVENESS

The following terms are necessary in understanding references in studies: separated from lab (lab work to discover new ideas, activities, games to supplement, and enrich class work); integrated into lab type (to introduce a topic of study, to review, to follow up ideas of a class with the whole class usually involved and working in small groups with similar materials and instructions); correlated with regular classroom lab type (directly related lab to curriculum with activity packets or lessons constructed for each topic).

Vance (1969) investigated a lab facility which was to function adjunct to the regular curriculum for 7th and 8th grades. The classes were working in pairs with written instructions; 6 classes rotated on a once a week basis in lab through 10

activity lessons. Testing showed this approach did not adversely affect achievement over a 3 month's period.⁽⁵⁹⁾

Wilkinson (1970) investigated an integrated math program teaching metric geometry to 6th graders. There were 15 days of lab work. This type of teaching was not shown to be statistically superior. But the method did appear more effective with middle and low intelligence students.⁽⁶⁰⁾

Johnson studied a program of a year long activity oriented lessons teaching number theory, geometry, measurement, and electronic calculators were employed to teach units on number theory and rational numbers. The study showed the performance of the students taught exclusively by the activity approach was inferior to the text based or activity enriched instruction.⁽⁶¹⁾

In a Canadian study, lab was used to teach measurement and skills to low-ability 9th graders. Several phases were used. First small groups used concrete aids. Also there was class discussion, problem lab sessions, and project lab sessions -- each designed for a specific purpose. Results indicated that the achievement of the students in the lab group significantly higher than those in the control group taught in the teacher-directed setting. Also student attitude was much better.⁽⁶²⁾

The use of concrete materials was studied by Fenema (1970). It was found such was no more effective than the symbolic model in the teaching of the principles of multiplication for 2nd graders. The lab was not criticized in the study, but for cognitive work, the teacher-class method appeared to work as well if not better. The principle carried through to higher-level operations such as transfer and the creative use of concrete materials. However, with low-ability students, concrete representations and lab approaches appeared only partially effective.

The Journal for Research in Math Education reported a study about the effects of activity-oriented instruction on original learning, transfer, and retention. The activity approach (lab) utilized manipulative materials for one group; another group (called Rote-Word) received lectures plus a verbalization of the problems to be solved; the other group was designated 'Rote' and received only lectures. The

control group received no instruction in the principles being taught. The post test and retention screen showed that there was no significant difference between the 3 techniques although all 3 groups showed an increase in learning as compared to the control group. (63)

In a doctoral dissertation at the University of Illinois, the lab approach of teaching long division was compared to the verbalized method using 4th graders from 10 separate schools (the students used the same problems and exercises). There was no significant difference in the two approaches. (64)

In another study, 4th graders from 8 different schools were studied. The discovery approach versus the expository (didactic) approach was used. The expository method was superior to the discovery method at the 0.05 level for both post test computation and retention. There was no significant difference on post tests of concepts, applications, and principles. Attitude was significantly better at the 0.01 level for the discovery treatment. (65)

Another study at the University of Connecticut found no difference in attitudes between 2 groups of 5th grade students, the first receiving the teacher-text approach, the second the individualized materials approach used with machines. The teacher-text method was found more effective for both achievement and time spent by the teacher in preparation of the materials. (66)

In an Ed.D dissertation study in 1970 the lab approach was compared with the didactic-instruction method. Both 7th and 8th graders were tested. One-half of the students used manipulative and multi-sensory materials while the rest were given the same concepts by a student centered teaching approach. The results showed no statistically significant increase in achievement for either the computational or the didactic method. Also there was no significant difference in either attitude or gain on a subtest of commonly taught content. (67)

In another study, attitude change was investigated with 8th grade students. The students were taught math in a math lab utilizing a math through science

approach. The investigator employed 18 attitudinal test batteries in an effort to establish a pre-test post-test comparison of attitude changes. Only 6 of the attitudinal test were found to be statistically significant ($p < .01$). For 5 of the 6, post-treatment test scores were lower than pretreatment mean scores, an indication of less favorable attitudes toward math after treatment than before treatment. In fact, the majority of the sample changed its attitude toward mathematics very little during the course of the study. Thus it would seem that, in general, strong cohesive attitude changes among students are not a factor for major consideration in developing or adapting mathematics taught by physical materials (lab) in the middle school. (68)

In a study done in North Carolina with kindergarden poverty children, Nicholas Anastasiow (1970) compared three distinct techniques. These included the discovery method in which no cuing was involved; and the didactic method which consisted of lecture and cuing. The results indicated that the didactic method may be the most efficient for mastery of the content taught in the early stages of the curriculum while the guided-discovery approach appears to be more efficient for mastery of more complex principles. It should be noted that the results of the post-test and retention tests did not support the efficiency of guided-discovery in comparison with the didactic teaching for the conditions under which the test was conducted. (69)

Donald Peters (1970) conducted a similar test with kindergarten children. His study also compared three distinct techniques: noncued discovery (NDC) which allowed no cuing; perceptual cue guided discovery (PCG) which used verbal cuing; and verbal didactic instruction (VID) which used verbal cuing. Thus, his techniques roughly paralleled those in the aforementioned study. In addition, Peters had a control group which received no instruction on the tested concept during the test period. His results were essentially the same as those in the study done by Anastasiow. The verbal didactic instruction was statistically better at the 0.05 level of significance. In addition, on the delayed retention test, there was no

statistically significant difference between the VDI and PCG. However, both were statistically superior to the NCD for the retention test. (70)

The use of specifically electronic devices, calculator or such also is revealing. Frederick Schippert (1965) found inner-city pupils who manipulated actual models or presentations of math principles showed significantly higher achievement on measures of skills than did others of traditional verbal teaching. (71)

Another study was conducted in Illinois. In that investigation, the two reasons for the use of calculators were investigated: motivation and achievement. Five classes of 20 students each (I.Q. 75-90) who had scored 2 years or more below grade level on achievement tests were studied. There were 2 teachers, 4 classes, one control group, and one experimental group. The results showed no improvement in the attitude toward math or computational skills. The control group did not use calculators at all. This was a 7-week study. (72)

Another early study used the RCA Instructional 70 System of the Spectra 70/45 computer at 42nd St. and 2nd Avenue in New York City. There were 16 experimental schools and 4 controlschools. But the five month study had non-controlled variables: selection of teachers, selection of schools, and number of hours of math instruction were not controlled. The evaluation of the CAI project in elementary arithmetic showed that the CAI students learned more than non-CAI students ($p < .01$). Further information can be obtained from: Director of CAI, Board of Education of the City of New York, 229 East 42 St., N.Y., N.Y. 10017. (73)

In another study, three algebra II classes at the Massachusetts Senior High School were taught the same math material by the same teacher. Students in two groups received instruction in flow charting and used this technique of designing and representating problem solutions graphically in doing their homework. Students in one of these two groups also learned computer programming and did their problems on the computer. The third group, which served as a control group, was taught in the traditional fashion -- lecture, classroom discussion, ordinary pencil and

paper homework assignments. The results were that the computer group scored twice as high as the control group on general scholastic ability and four times as high on a reasoning test. Implications of this experiment were that students are able to learn more in less time when the computer was properly utilized in the educational process. The reason is not understood. The most prevalent idea is that the student is utilizing the computer and is being taught how to apply his or her own logic to the solution of the various problems. (74)

Overall, the studies cited in this report show that the lab approach was superior in 44% of the studies. Furthermore, there was no difference in the laboratory and expository (didactic) methods in 44% of the studies. Finally, the didactic approach was superior in 12% of the studies.

The groups studied were represented in the following divisions: elementary schools (57%), middle schools (28%), and high schools (14%). The superiority of the laboratory approaches were distributed across all grade levels as were studies reporting no difference in the laboratory and expository methods of teaching. Furthermore, no specific variables were found to explain the achievement differences between the laboratory and traditional groupings. It is known, however, that not all teachers can manage a laboratory approach. These teachers are more traditional in their teaching approaches as opposed to more of a manager of teaching activities.

Finally, computer use has greatly increased in education and is of great importance in mathematics laboratories. As would be expected, a recent national Task Force on Education and Technology has found that there is a great deal of interest in computer use. However, in assessing technology's link to the schools, the task force made the following recommendations: (1) closer collaboration between computer developers, computer users, and those providing money for the systems; (2) those using the computers, such as teachers and parents, should work to influence major state and federal policy decisions affecting the use of computers in the schools; and (3) money should be set aside for training and new technology such as computers. (75) Clearly the computer is

a tool to help students learn logical thinking skills. Perhaps this summary also best characterizes the laboratory and CAI programs. Both are valuable tools when used in the educational environment.

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